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# Density of State Mass Dependent Optical Phase Conjugation in Direct Gap Semiconductors via Stimulated Brillouin Scattering

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***Abstract*-** We develop a theoretical model to study density of state mass dependent Optical Phase Conjugation via Stimulated Brillouin Scattering (OPC-SBS) in direct gap semiconductors. An empirical formula based on phenomenological model is used to determine the maximum possible plasma density in terms of density of state mass in the medium which is used in deriving third order susceptibility using coupled mode scheme and hydrodynamical model. Extensive numerical estimates have been performed to appreciate the DOS dependency of OPC process in InSb, CdS and GaAs crystals shined by119 $\mu m$ pulsed $H_2O$ laser at 300K. Threshold value of pump electric field, the possibility of optical phase conjugation and the corresponding interaction length is to be premeditated. The maximum possible plasma density is found to be highest in CdS and lowest in InSb crystals. Hence the analysis reveals that higher the density of state mass lower is the interaction length. CdS is found to be most appropriate host for the (OPC-SBS) process with highest gain coefficient and with lower interaction length. On the other hand if the crystal is used as an optical waveguide with relatively large interaction length then InSb proves its potential in practical applications such as fabrication of phase conjugate mirrors.

***Index Terms*-** Density of State mass, Phase Conjugation, Semiconductors, Stimulated Brillouin scattering.

## I. INTRODUCTION

A Highly directional laser beam is scattered "Splashed" into smaller beams of different directions when it passes through a medium whose refractive index has irregular inhomogenities. As in the case of a sine projector if we succeed in reversing time, a "Shaggy" light beam approaches the inhomogeneous medium and becomes ideally directionally after passing it. It is interesting that in optics such a procedure i.e. time reversal can indeed be realized. A number of methods for generating a phase conjugated wave have been suggested and realized in recent decades. The optical situation is favourable in two aspects. First the high transparency of optical media provides insignificant dissipation which would lead to time irreversibility. Second in coherent optics it is possible to define positions and directional amplitudes and phases of elementary rays that provide a detailed reproduction of the propagation of the reversed wave.

Basically there are three major classes of nonlinear optical interactions used to obtain OPC. They are optical parametric mixing, Stimulated Scattering processes and hybrid schemes [1]. The most commonly used techniques involving these interactions are: degenerate four-wave mixing (DFWM), stimulated Brillouin scattering (SBS) and Brillouin-enhanced four-wave mixing (BEFWM). Optical phase conjugation via stimulated Brillouin scattering (OPC-SBS) has been shown to have distinct advantages over other stimulated scattering processes because of the facts that: (i) it is nearly steady-state process: (ii) it requires relatively low excitation intensity, and (iii) suffers a negligible frequency shift [2]. Stimulated Brillouin scattering is a third order nonlinear optical phenomenon caused by coherent interaction of an intense pump, scattered and acoustic waves in Brillouin medium. The internally generated acoustic and scattered waves propagate along specific directions and amplify when the intensity of pump beam exceeds a threshold value [3].

OPC-SBS was first observed in an optical waveguide by Zel-dovich [4] in 1972 using a capilliary tube with methane gas. Later on through this model, Zel-dovich showed that these phase conjugated beams experience preferential gain over all other mode combinations for reflection of the signal. In the earlier period, SBS has been extensively investigated due to its important property of OPC that can be exploited to recover the phase front of beam, and thus improve the beam quality [5-8]. Sen et al. researched on OPC in narrow direct gap semiconductor [9]. N. Nimje and S. Ghosh currently studied Optical Phase Conjugation Reflectivity in acousto-optic semiconductor plasma crystal and obtained 72% reflectivity of phase conjugated wave [10]. Recently Hai Lu worked on the OPC enhancement in one dimensional nonlinear photonic crystals containing single negative materials [11]. Optically tunable compensation of nonlinear signal distortion in optical fiber by end span optical phase conjugation has been dealt by D. Mark and his coworkers [12]. N. Papadopoulos et al. has focussed and scanned the light through a multimode optical fiber using digital phase conjugation. The recent publication of our group [13] reveals the effects of material parameter on interaction length to occur optical phase conjugation via stimulated Brillouin scattering in semiconductors.

Present analysis is based on coupled mode theory for investigating the density of state mass dependent OPC-SBS due to four wave mixing process incorporating band structure and hot carrier effects. The inclusion of density of states mass through band structure and carrier temperature adds new dimensions to

the present study. Initially the crystal temperature is assumed to be maintained at room temperature (300K), therefore the transfer of energy and momentum of carriers occurs through their collisions with polar optical phonons (POP) and acoustic phonons (AP) respectively [14]. In the present case, the nonlinearity is solely due to the induced nonlinear current density of free carriers. The third order nonlinear optical susceptibility $\chi^{(3)}$ responsible for the occurrence of SBS process has been obtained following coupled mode scheme under hydrodynamic regime. However, as far as we know, no such attempt has been made to determine threshold value of pump electric field, the possibility of optical phase conjugation and the corresponding interaction length in direct gap semiconductor plasmas incorporating the density of states mass of free carriers.

## II. THEORITICAL FORMULATION

This This section deals with the theoretical formulation of the third order nonlinear optical susceptibility $\chi^{(3)}$ for stokes component of the scattered electromagnetic wave in doped semiconductors. We have considered the well known hydrodynamical model of homogenous one component plasma (electron) under thermal equilibrium. In order to study the effective Brillouin susceptibility arising due to nonlinear susceptibility $\chi^{(3)}$ and the electrostrictive polarization, the spatially uniform pump electric field $E_0 \exp(-i\omega_0 t)$ is applied parallel to the wave vector k (along the x axis). As the crystal is assumed to be centrosymmetric, the effect of any pseudopotential can be neglected for analytical simplicity. We have employed the coupled mode scheme to obtain the nonlinear polarization arising due to electrostrictive strain.

The basic equations considered for the analysis are:

$$\frac{\partial^2 u(x,t)}{\partial t^2} - \frac{C}{\rho}\frac{\partial^2 u(x,t)}{\partial t^2} + 2\Gamma_a \frac{\partial u(x,t)}{\partial t} = \frac{\gamma}{2\rho}\frac{\partial}{\partial x}(E_0 E_1^{*}) \quad (1)$$

$$\frac{\partial v_0}{\partial t} + \nu v_0 = \frac{e}{m}E_0 \quad (2)$$

$$\frac{\partial v_1}{\partial t} + \nu v_1 + v_0\frac{\partial v_1}{\partial x} = \frac{e}{m}E_1 \quad (3)$$

$$\frac{\partial n_1}{\partial t} + v_0\frac{\partial n_1}{\partial x} + n_0\frac{\partial v_1}{\partial x} = 0 \quad (4)$$

$$P_{es} = -\gamma E_0 \frac{\partial u^{*}}{\partial x} \quad (5)$$

$$\frac{\partial E_1}{\partial x} = \frac{n_1 e}{\varepsilon} + \frac{\gamma}{\varepsilon}E_0\frac{\partial u^{*}}{\partial x} \quad (6)$$

The Equation (1) represents the equation of motion of generated acoustic wave in centrosymmetric medium, where $u(x,t) = u\exp\{i(k_a x - \omega_a t)\}$ is the lattice displacement. $\rho$, $\Gamma_a$, $\gamma$ and C are the material density, phenomenological damping constant, electrostriction coefficient and elastic constant of the medium, respectively. $E_1$ is the space charge electric field. Right hand side of the equation (1) defines the effect of electrostriction. Equations (2) and (3) describe the zeroth and first order electron momentum transfer equations in which m and $\nu$ represent the effective mass and phenomenological momentum transfer collision frequency of electrons. Conservation of charge is represented by the continuity equation (4) in which $n_0$ and $n_1$ are the equilibrium and perturbed electron densities, respectively. Equation (5) describes that the acoustic wave generated due to electrostrictive strain, modulates the dielectric constant and give rise to a non linear induced eletrostrictive polarization $P_{es}$. At a frequency that is large compared to the frequencies of motion of electrons in the medium, the polarization of the medium is considered neglecting the interaction of the electron with each other and with the atomic nuclei. The space charge field $E_1$ is determined from Poisson's equation (6) in which last term on R.H.S. represents the contribution of electrostrictive polarization where $\varepsilon = \varepsilon_0\varepsilon_1$; $\varepsilon_1$ is the lattice dielectric constant and $\varepsilon_0$ is its absolute permittivity.

### A. *Carrier Temperature and Momentum Transfer Collision Frequency (MTCF)*

The The fundamental requirement to insite SBS is, the applied pump field must be well above certain amplitude known as threshold amplitude. When this high intensity pump field interacts with a high mobility semiconductor, carriers acquire momentum and energy from the pump and consequently carriers acquire a temperature ($T_e$) somewhat higher than that of the lattice temperature ($T_0$). In steady state, the carrier temperature $T_e$ can be readily obtained from energy balance equations as follows. The power absorbed per carrier from pump electric field is obtained from equation (2) as

$$\frac{e}{2}\mathrm{Re}(v_0 E_0^{*}) = \frac{\nu e^2 E_0 E_0^{*}}{2m\left(\nu^2 + {\omega_0}^2\right)} \quad (7)$$

Where "$*$" denotes the complex conjugate of the quantity and "Re" denotes the real part.

Following conwell [15] the power dissipation per electron (carrier) in collisions with the polar optical phonon (POP) may be expressed as

$$\langle p\rangle_{pop} = \left(\frac{2K_B\theta_D}{m\pi}\right)^{1/2} eE_{PO}{x_e}^{1/2}K_0\left(\frac{x_e}{2}\right)\exp\left(\frac{x_e}{2}\right)\frac{\exp(x_0 - x_e) - 1}{\exp(x_0) - 1} \quad (8)$$

where $x_{0,e} = \frac{\eta\omega_1}{K_B T_{0,e}}$ in which $\eta\omega_1$ is the energy of POP given by $\eta\omega_1 = K_B\theta_D$ and $\theta_D$ is the Debye temperature of the medium $E_{PO} = \frac{mc\eta\omega_0}{\eta^2}\left(\frac{1}{\varepsilon_\infty} - \frac{1}{\varepsilon_L}\right)$ is the field of POP scattering potential in which $\varepsilon_1$ and $\varepsilon_\infty$ are the static and high frequency dielectric permittivities of the medium, respectively, $K_0\left(\frac{x_e}{2}\right)$ is the zeroth-order Bessel function of first kind.

In steady state, the power absorbed per carrier from the pump electric field is just equal to the power dissipation per carrier in collision with POP scattering. Therefore, for moderate heating of carrier (i.e. $T_e \approx T_0$) by pump electric field, using equations (7) and (8), we yield

$$\frac{T_e}{T_0} = 1 + \frac{e^2 \nu}{2m} \frac{\tau E_0 E_0^*}{\left(\nu^2 + {\omega_0}^2\right)} \tag{9}$$

Where $\tau^{-1} = \left(\frac{2K_B\theta_D}{m\pi}\right)^{1/2} eE_{PO} x_0 K_0\left(\frac{x_0}{2}\right) \frac{{x_0}^{1/2} \exp\left(\frac{x_0}{2}\right)}{\exp(x_0) - 1}$

This heating of carriers modifies the momentum transfer collision frequency (MTCF) due to acoustic phonon scattering as

$$\nu = \nu_0 \left(\frac{T_e}{T_0}\right)^{1/2} \tag{10}$$

in which $\nu_0$ is the MTCF of carrier in absence of pump electric field.

### *B. Band structure dependence of the electron hole plasma density*

Forchel et al. [16] have investigated systematically the relation of the maximum plasma density in a direct gap semiconductor as a function of band structure and temperature. For a one component plasma, they have shown analytically that n increases with the density of states mass $m_d$ and the temperature as $(m_d T)^{3/2}$. For the ambipolar diffusion of electron hole plasma the relation

$$n = 4.2 \times 10^{22} \left(\frac{m_{de} m_{dh}}{m_{de} + m_{dh}}\right)^{\frac{3}{2}} T^{3/2} \tag{11}$$

is reported to be a good approximation numerically. Physically this relation means that the density maximum is related to a constant degeneracy of the plasma; it occurs for effective degeneracy's close to two, for which the plasma transport is significantly, affected by both, temperature and density gradients. They have reported that experimentally observed band structure dependence of the reduced densities in direct gap semiconductors is same as the band structure variation of the non equilibrium electron hole plasma observed in the indirect gap materials. They have discussed that for all direct and indirect gap materials. The induced plasma densities are in good agreement with their productions using the thermo-diffusion model.

### *C.Induced current density and effective third order susceptibility*

A carrier density perturbation is produced within the Brillouin active medium due to electrostrictive force. In highly doped semiconductor, these density perturbations in terms of coupled fields can be obtained by the standard approach Using equations (1) to (6) and neglecting the Doppler shift under the assumption that $\omega_0 >> \nu > \rho k_0 \rho v_0$, one obtains

$$\frac{\partial^2 n_1}{\partial t^2} + \nu \frac{\partial n_1}{\partial t} + {\omega_p}^2 n_1 + \frac{ik\gamma E_0 e n_0 u^*}{m\varepsilon} = -\overline{E} \frac{\partial n_1}{\partial x} \tag{12}$$

where $\omega_p = \left[\frac{ne^2}{m\varepsilon}\right]^{1/2}$ is carrier plasma frequency of the medium.

The perturbed electron concentration $n_1$ will have two components due to the electrostrictive interaction within the medium. It may be recognized as slow $(n_s)$ and fast $(n_f)$ components, respectively. The slow component $n_s$ is associated with low frequency acoustic wave $\omega_a$ and varies as $\exp[i(k_a x - \omega_a t)]$, whereas the fast component $n_f$ oscillates at high frequency $(\omega_0 \pm \omega_a)$ of electromagnetic wave and varies as $\exp[i(k_0 \pm k_a)x - (\omega_0 \pm \omega_a)t]$. The higher order terms with frequency $\omega_0 \pm p\omega_a$ (p=2, 3, 4) being off resonant are neglected by assuming the interaction path as sufficiently long and only the first order Stoke's component (p=1) has been considered.

In the Stimulated Brillouin process, the phase matching conditions, which are follows:

$$h\omega_0 = \eta\omega_1 + h\omega_a \tag{13a}$$

$$\eta \rho k_0 = \eta \rho k_1 + \eta \rho k_a \tag{13b}$$

These are known as the energy and momentum conservation relations. Here we have considered only the Stoke's component of the scattered electromagnetic wave for which phase matching condition becomes $\omega_1 = \omega_0 - \omega_a$ and $k_1 = k_0 - k_a$.

We could neglect the nonuniformity of the high frequency electric field under dipole approximation when the excited acoustic and Stoke's waves have wavelengths, which are small compared to the scale length of the electromagnetic field variation and it has been assumed $\left|\rho k_a\right| \ (\approx \rho k) \rangle \rangle \left|\rho k_0\right|$ without any loss of generality.

We may obtain the following coupled wave equations under rotating wave approximation (RWA) [17] as

$$\frac{\partial^2 n_{1s}}{\partial t^2} + \nu \frac{\partial n_1}{\partial t} + n_{1s}\omega_p = -E_0 \frac{e}{m} \frac{\partial {n_1}_f^*}{\partial x} \tag{14a}$$

$$\frac{\partial^2 n_{1f}}{\partial t^2} + \nu \frac{\partial n_{1f}}{\partial t} + n_{1f} {\omega_p}^2 - \frac{n_0 \gamma k^2 u^*}{\varepsilon} \frac{e}{m} E_0 = \frac{-e}{m} E_0 \frac{\partial n_{1s}^*}{\partial x} \tag{14b}$$

In the above equations, the subscripts "s" and 'f" stands for slow and fast components, respectively.

It may be inferred from equations (14) that the generated slow and fast components of density perturbation are coupled to each other via the pump electric field. Hence, it is obvious that the presence of pump electric field is the fundamental necessity for SBS to occur. From equations (14), one may obtain

$$n_{1s} = \frac{ikn_0\gamma u}{\varepsilon} \left[1 - \frac{\left(\delta_1^2 + i\omega_1\nu\right)\left(\delta_1^2 - i\omega_a\nu\right)}{k^2 {E_0}^2 e^2 / m^2}\right]^{-1} \tag{15}$$

It is evident from equation (15) the above that $n_{1s}$ depends upon the magnitude of the pump intensity $I = \left(\frac{1}{2}\right)\eta\varepsilon_0\varepsilon|E_0|^2$ with $\eta$, $\varepsilon_0$ and c being the background refractive index of the crystal, absolute permittivity and velocity of light. The density perturbation thus produced affects the propagation

characteristics of the generated wave where, $\delta_1^2 = \omega_P^2 - \omega_a^2$ and $\delta_2^2 = \omega_p^2 - \omega_a^2$; and the other symbols have their usual meanings. .

Now the Stoke's component of the induced nonlinear current density may be obtained from the relation.

$$J_1(\omega_1) = n_{1s} \bullet e v_0 \tag{16}$$

Which yields

$$J_1(\omega_1) = \frac{i\omega_p^2 \varepsilon E_{1x}(\omega_1)}{\omega_0^2} - \frac{i\gamma^2 k^2 \omega_p^2 \omega_0^2 |E_0|^2}{2\rho\omega_0(\omega_0)^2(\omega_a^2 - k^2 v_a^2 + 2i\Gamma_a\omega_a)}\left[1 + \frac{(\delta_1^2 - i\omega_1\nu)(\delta_2^2 + i\omega_a\nu)}{k^2 E_0^2 e^2/m^2}\right]^{-1} \tag{17}$$

The induced nonlinear polarization $p_{cd}(\omega_1)$ may be treated as the time integral of the induced nonlinear current density $J_1(\omega_1)$ i.e.

$$P_{cd}(\omega_1) = \int J_1(\omega_1)dt = \frac{-J_1(\omega_1)}{i\omega_1} \tag{18}$$

Using equations (17), the induced nonlinear polarization $P_{cd}(\omega_1)$ is obtained as

$$P_{cd}(\omega_1) = \frac{\gamma^2 k^2 \omega_p^2 \omega_0^2(\omega_1)}{2\rho\omega_0\omega_1(\omega_0)^2(\omega_a^2 - k^2 v_a^2 - 2i\Gamma_a\omega_a)}\left[1 + \frac{(\delta^2 1 - i\omega_1\nu)(\delta_2^2 + i\omega_a\nu)}{k^2 E_0^2 e^2/m^2}\right]^{-1} E_0 E_0^* E_1(\omega_1) \tag{19}$$

The threshold pump amplitude for the onset of SBS may be obtained by setting $P_{cd}(\omega_1) = 0$ in equation (19) as

$$|E_{0th}| = \frac{m}{ek}\left[(\delta_1^2 - i\omega_1\nu)(\delta_2^2 + i\omega_a\nu)\right]^{1/2} \tag{20}$$

Hence the interaction between the pump and centrosymmetric crystal will be dominated by the SBS phenomena at a pump power level well above the threshold field. From equation (20), we may infer that $E_{0th}$ strongly depends on material parameters, wave number.

Besides the induced polarization at Stoke's mode $P_{cd}(\omega_1)$, the system should also possess an electrostrictive polarization $P_{es}(\omega_1)$ arising due to the interaction of the pump wave with the acoustic wave generated in the medium. This is due to the fact because the scattering of light from the acoustic mode affords a convenient mean to control the frequency, intensity and direction of optical beam. This type of control makes possible a large number of applications involving the transmission, display and processing of information. This electrostrictive polarization is obtained from equations (1) and (5) as,

$$P_{es}(\omega_1) = \frac{k^2\gamma^2 E_0 E_0^* E_1(\omega_1)}{2\rho(\omega_a^2 - k^2 v_a^2 - 2i\gamma_a\omega_a)} \tag{21}$$

Thus, the total induced polarization at the Stoke's component in a Brillouin active medium is given by

$$P(\omega_1) = p_{cd}(\omega_1) + p_{es}(\omega_1) = \frac{\varepsilon_0\gamma^2 k^2}{2\rho\varepsilon_0(\omega_a^2 - k^2 v_a^2 - 2i\Gamma_a\omega_a)}\left[1 + \frac{\omega_p^2}{\omega_0\omega_1}\right] \tag{22}$$

The effective polarization induced by the intense pump in a centrosymmetric semiconductor may be expressed as

$$P(\omega_1) = \varepsilon_0 \chi_B^{(3)} E_0 E_0^* E_1(\omega_1) \tag{23}$$

Comparing equations (22) and (23), one may obtained third order susceptibilities as

$$\chi_B^{(3)} = \frac{\gamma^2 k^2}{2\rho\varepsilon_0(\omega_a^2 - k^2 v_a^2 - 2i\Gamma_a\omega_a)}\left[1 + \frac{\omega_p^2}{\omega_0\omega_1}\right] = (\chi_B^{(3)})_{real} + (\chi_B^{(3)})_{img} \tag{24}$$

where subscripts "*real*" and "*img*" stand for the real and imaginary parts of the effective third-order susceptibility in the Brillouin active medium.

*D. Steady state Brillouin gain of Stoke's wave*

In order to investigate the steady state Brillouin gain of the Stoke's component in the presence of the pump amplitude well above the threshold pump field, we use the following relation

$$g(\omega_1) = \frac{-k}{2\varepsilon_1}\left[\chi_B^{(3)}\right]_{img}|E_0|^2 \tag{25}$$

Using equations (24) and (25), we yield

$$g(\omega_1) = \frac{\gamma^2 k^3 |E_0|^2}{8\rho\varepsilon_0\varepsilon_1\omega_a^2\Gamma_a}\left[1 + \frac{\omega_p^2}{\omega_0\omega_1}\right] \tag{26}$$

Now this relation may be used for computing the effect of band structure dependent plasma density on the growth rate of Brillouin scattered mode in Brillouin active centrosymmetric semiconductor crystal to study the effect of band structure dependent plasma density.

*E. Interaction Length*

**SBS** in a material do not generate a perfect phase conjugate beam. As a result of the interaction with phonon wave in the material, the stokes beam shifted in frequency of the 10GHz. This small frequency shift leads to a limitation in the length of the material that can be used to generate a phase conjugate beam. Since SBS phase conjugation derives from the selected gain of the conjugate mode, Stokes beam must overlap the signal wave

path exactly to experience the gain from the speckle pattern from the signal wave. The frequency shift of the Stokes beam thus limits the interaction length for good phase conjugation. The minimum interaction length that can be used to achieve a specified quality of optical phase conjugation via stimulated Brillouin scattering (OPC-SBS) was modelled by Zel'dovich [19]. Following Zel'dovich [19] and using equation (26) one obtains

$$L = \frac{30}{g(\omega_1)} \qquad (27)$$

Now this relation shall be used to compute the interaction length for analysing the density of state mass dependent OPC-SBS in direct gap semiconductor plasmas. From the above equation it is clear that the possibility of OPC strongly depends on density of states mass of free carriers.

## III. RESULT AND DISCUSSION

This section aims to make a detailed numerical appreciation of the analytical investigation made in above section. The semiconductor bulk crystals used for this purpose are CdS, (Hexagonal) and GaAs, InSb (tetrahedral) respectively. Thus stimulation for the selection of these crystals for the SBS analysis stems from the extensive technological applications. We have considered irradiation of these crystals by pulsed 119 μm $H_2$ O laser. The other relevant parameters at room temperature used are; For InSb $\eta = 3.9,\ m_{de} = 4.2\times10^{22} m_0 m^{-3},$ $m_{dh} = 7.3\times10^{24} m_0 m^{-3},\quad \rho = 6.8\times10^{3} kgm^{-3},\quad \Gamma_a = 2\times10^{10} s^{-1},$ $\nu_a = 4.8\times10^{3} ms^{-1},\quad \nu = 3\times10^{11} ms^{-1};$ For GaAs $m_{de} = 4.7\times10^{23} m_0 m^{-3},\quad m_{dh} = 9.8\times10^{24} m_0 m^{-3},;$ For CdS $m_{de} = 1.5\times10^{25} m_0 m^{-3},\ m_{dh} = 1.2\times10^{25} m_0 m^{-3}.$

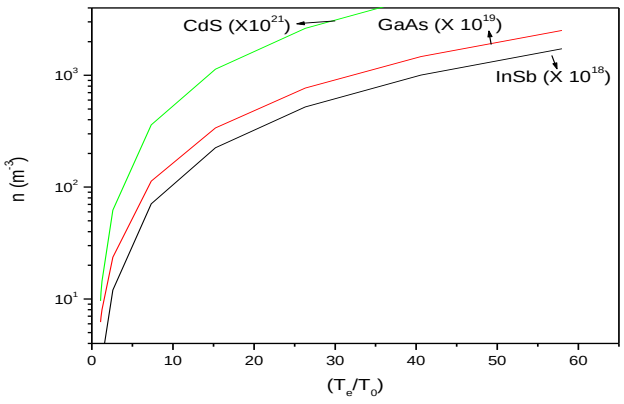


Figure 1: Variation of maximum plasma density $(n)$ with electron to lattice temperature $(T_e/T_0)$.

Figure 1: depicts the qualitative behaviour of the variation of maximum possible plasma density $(n)$ with carrier temperature $T_e/T_0$ for the three direct gap semiconductors under study. In all the three cases maximum possible plasma density increases with temperature. It is found to be highest in CdS of the order of $(\approx 10^{21} m^{-3})$ and lowest in InSb $\left(\approx 10^{18} m^{-3}\right)$ crystals. Hence one can conclude (13) that higher the density of state mass higher is the maximum possible plasma density.

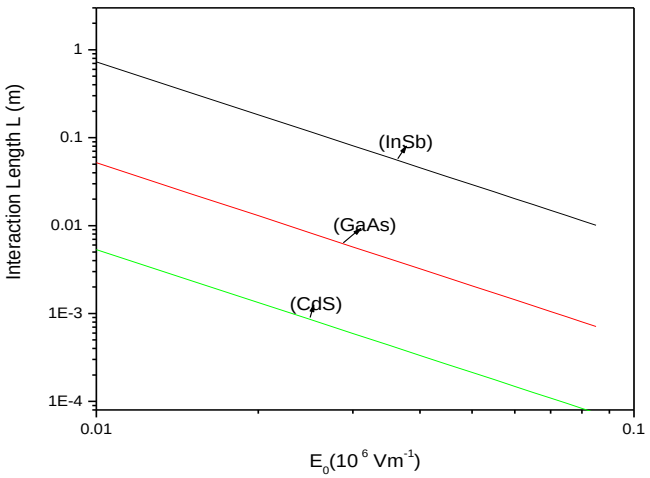


Figure 2: Variation of Interaction length $(L)$ with Pump amplitude $E_0$ at $k = 10^7 m^{-1}$.

Figure 2: Shows the dependence of interaction length on input pump amplitude. In this figure, we illustrate the nature of dependence of interaction length L on pump amplitude in three direct gap semiconductors (InSb, GaAs, CdS). As reported in the article [20] that in the absence of magnetic field, when $B_0 = 0.0T$ a large $L$ is required to occur OPC-SBS. On the basis of above we may plot a graph between pump amplitude and interaction length at input intensity $I_{in} = 10^{12} W m^{-1}$ for the three direct gap semiconductor crystals and we found that as we increase the pump amplitude, interaction length decreases for the three semiconductors.

Comparison of the three curves reveals that interaction length to occur OPC-SBS is minimum for CdS having higher density of state mass. It may be bear in mind that $I_{in}$ should always be less than the damage threshold of crystal.

The Figure 3 shows the dependence of interaction length $(L)$ on wave number $k$ at excitation intensity $I_{in} = 10^{12} W m^{-1}$. It can be inferred from this figure that if we increase wave number $k$ then interaction length decreases upto $k = 4\times10^{6} m^{-1}$ and after this it becomes constant. The same behaviour is shown for the three semiconductor crystals. Again there is a same result as previous, having minimum interaction length for CdS having higher density of state mass and the value of interaction length is higher for InSb.

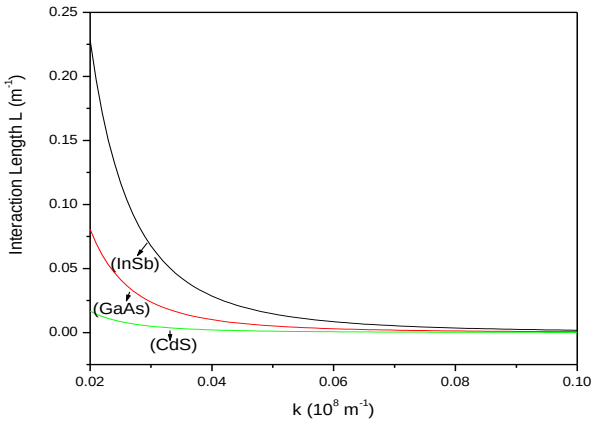


Figure 3: Variation of Interaction length $(L)$ with wave vector $k$ at pump amplitude $E_0 = 1\times10^{6} Vm^{-1}$.

## IV. CONCLUSION

The above study establishes that particularly in direct gap semi conductors while studying laser plasma interaction one must incorporate density of state mass to achieve better agreement between theoretically predicted and experimentally observed values. Thus we conclude that the semiconductor crystal having higher density of state mass is having lower interaction length (CdS) which is having very potential applications in making optical conjugate mirrors.

## REFERENCES

[1] D. M. Pepper, in: M. L. Stitch, M. Bass (Eds.), " Nonlinear Optical phase conjugation " Laser Handbook, Elsevier, Amsterdam, 1985, pp. 333-467.

[2] S. A. Shakir, "Increasing the efficiency of Stimulated scattering phase conjugate Mirrors ", Proc. SPIE 540, 1985, pp. 303-316.

[3] R. L. Sutherland, Handbook of Nonlinear Optics, Marcel Dekker, London, 2003, ch. 13, pp. 670-676.

[4] B. Y. Zel,d ovich, V. I. Popovichev, V. V. Ruagul'skii, F. S. Faizullov, "Long-term stabilized two-beam combination laser amplifier with stimulated Brillouin scattering mirrors", Sov. Phys. JETP Lett. 15, 1972, pp. 109-111.

[5] M. Ostermeyer, H.J. Kong, V.I. Kovalev, R.G. Harrison, A.A. Fotiadi, P. ME´ Gret, M. Kalal, O. Slezak, J.W. Yoon, J.S. Shin, D.H. Beak, S.K. Lee, Z.Lü, S. Wang, D. Lin, J.C. Knight, N.E. Kotova, A. Sträßer, A. Scheikh-Obeid, T. Riesbeck, S. Meister, H.J. Eichler, Y. Wang, W. He, H. Yoshida, H. Fujita, M. Nakatsuka, T. Hatae, H. Park, C. Lim, T. Omatsu, K. Nawata, N. Shiba, O.L. Antipov, M.S. Kuznetsov, N.G. Zakharov, "Restoration of high spatial frequency at the image formed by stimulated Brillouin scattering with a prepulse", Laser Part. Beams 26, 2008, pp. 1-66.

[6] G. J. Grofts, M. J. Damzen, R. A. Lamb, " Experimental and theoretical investigation of two-cell stimulated-Brillouin-scattering systems", J. Opt. Soc. Am. B 8, 1991, pp. 2282-2288.

[7]. J. Bai, J. Shi, M. Ouyang, X. Chen, W. Gong, H. Jing, J. Liu, D. Liu, "Experimental investigation on the competition between wideband stimulated Brillouin scattering and forward stimulated Raman scattering in water", Opt. Lett. 33 2008, pp. 1539.

[8] Z. W. Lu, W. L. J. Hasi, H. P. Gong, Q. Li, W. M. He, "Generation of flat-top waveform by double optical limiting based on stimulated Brillouin scattering", Opt. Exp. 14 2006, pp. 5497-5508.

[9] Y. L. Wang, Z.W. Lu, Y. Li, P. Wu, Z. X. Zheng, W. M. He, "A new circulating two-cell structure for stimulated Brillouin scattering phase conjugation mirrors with 1-J load and 10-Hz repetition rate **",** Appl. Phys. B 98 , 2010, pp. 391.

[10] P. K. Sen, P. Sen, "Optical phase conjugation in narrow direct-gap semiconductors", J. Appl. Phys. 63, 1988, pp. 4637.

[11] N. Nimje and S. Ghosh, "Optical phase conjugation reflectivity via stimulated Brillouin scattering in acousto-optic diffusive semiconductor plasma crystal", J. Phys.: Conf. Ser. 365, 2012, 012043.

[12] H. Lu, C. Xue, H. Tiang, H. Chen, "Growth and nonlinear optical properties of BaAlBO3F2 crystal," Josa B 28, 2011, pp. 856-866.

[13] D. Mark, P. Benjamin, J. Eggleton, "Optically tunable compensation of nonlinear signal distortion in optical fiber by end-span optical phase conjugation",Optics Exp. 20, 2012, pp. 8015.

[14] N. Papadopoulos, S. Farahi, C. Moser, D. Pialles, "Experimental measurement of the number of modes for a multimode optical fiber", Optics Exp. 20, 2012, pp. 10583.

[15] S. K. Sharma, "Hot-electron galvano-thermo-magnetic transport properties of III–V semiconductors at low temperatures (II) ", Phys. Stat. Sol. (a) **9,** 1972 pp. 275-281.

[16] E. H. Miller, "A note on reflector arrays (Periodical style—Accepted for publication)," *IEEE Trans. Antennas Propagat.*, to be published.

[17] J. E. M. Conwell, High Field Transport in Semiconductor, Academic Press, New York, 1967.

[18] K. Shimoda, "Introduction to Laser Physics", Springer-Verlag, Berlin, 1982.

[19] B. Y. Zel'dovich, N. F. Pilipetsky, V. V. Shkunov, "Principles of Phase Conjugation", Springer-Verlag, Berlin 1985.

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